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Vegetation Management in Canadian Forestry

R. F. Sutton

Information Report O-X-369
Great Lakes Forest Research Centre

86-0614/

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VEGETATION MANAGEMENT IN CANADIAN FORESTRY

R.F. SUTTON

GREAT LAKES FOREST RESEARCH CENTRE

CANADIAN FORESTRY SERVICE

GOVERNMENT OF CANADA

1985

INFORMATION REPORT O-X-369

©Minister of Supply and Services Canada 1985
Catalogue No. Fo46-14/369E
ISBN 0-662-14074-5
ISSN 0822-210X

Additional copies of this publication are available at no charge from:

Communications Services
Great Lakes Forest Research Centre
Canadian Forestry Service
Government of Canada
P.O. Box 490
Sault Ste. Marie, Ontario
P6A 5M7

ABSTRACT

Vegetation management in Canadian forestry is reviewed. The importance of the forest industry to Canada's economy is outlined and the need to intensify forest management if economic benefits are to continue is stressed. Factors governing the choice of method of vegetation control and determining the advantages and disadvantages of eacn method for the type of control needed are discussed. With respect to herbicides, a distinction is drawn between herbicidal efficacy (the capacity of a herbicide to cause direct phytotoxic effects in weeds) and silvicultural efficacy (the capacity of a herbicide indirectly to promote positive growth responses in crop trees); efficacy is then examined in relation to site preparation, cleaning, and release. The peculiarity of problems of cost-risk-benefit analysis applied to forest vegetation management is emphasized, especially those aspects of such analysis that contrast with those related to agriculture.

RÉSUMÉ

L'auteur passe en revue la gestion de la végétation en foresterie au Canada. Il souligne l'importance de l'industrie forestière pour l'économie canadienne ainsi que la nécessité d'intensifier l'aménagement forestier en vue de garantir des avantages économiques durables. Il discute des facteurs qui influent sur le choix des méthodes de lutte contre la végétation et servent à déterminer les avantages et les inconvénients de chaque méthode. Il établit une distinction entre l'efficacité des herbicides comme désherbants (effet phytotoxique direct sur les mauvaises herbes) et l'emploi de ces produits pour des fins sylvicoles (pour favoriser indirectement la croissance des arbres de peuplement final), et il étudie ensuite l'efficacité en rapport avec la préparation et le dégagement du sol. Il met en relief le caractère particulier des problèmes de l'analyse coûts-risques-avantages appliquée à la gestion de la végétation forestière, notamment les aspects de cette analyse qui contrastent avec ceux qui se rapportent à l'agriculture.

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Note: The exclusion of certain manufactured products does not necessarily imply disapproval nor does the mention of other products imply endorsement by the Canadian Forestry Service.

COVER PHOTOS

Top left:

Aerial glyphosate treatment at Carnation Creek Experimental Watershed, Vancouver Island: Bell-47 helicopter fitted with MICROFOIL BOOM® for drift control to protect salmon streams. Photo by P.D. Kingsbury, Forest Pest Management Institute, Canadian Forestry Service.

Middle left:

Experimental manual breaking of deciduous shrub and sapling vegetation near Chapleau, Ontario. Photo by R.F. Sutton. *See* Sutton, R.F. 1984. Plantation establishment in the boreal forest: glyphosate, hexazinone, and manual weed control. For. Chron. 69:283-287.

Bottom left:

Hexazinone Gridball™ placed on the forest floor. Photo by R.F. Sutton. *See* Sutton, R.F. 1985. Hexazinone Gridballs™ applied with concurrent underplanting of white spruce in boreal mixedwoods: 7-year results. In preparation.

Centre:

White spruce seven growing seasons after outplanting as 2+2 stock on moist loamy sand in eastern Ontario; 7th-year height increment 61 cm. Initial weed control treatment amino triazole + simazine. Photo by R.F. Sutton. *See* Sutton, R.F. 1968. Ecology of young white spruce *(Picea glauca* [Moench] Voss). Ph.D. thesis Cornell Univ., Univ. Microfilms 68-11645.

Top right:

The Donaren powered disc trencher on McChesney Lumber limits near Foleyet, Ontario. Photo by R.F. Sutton.

Middle right:

The Ås motorized backpack mistblower for foliar application of pesticide. Photo by R.F. Sutton *See* Sutton, R.F. 1984. Plantation establishment in the boreal forest: glyphosate, hexazinone, and manual weed control. For. Chron. 60:283-287.

Bottom right:

Young's teeth mounted on the straight blade of a bulldozer engaged in mechanical site preparation near Manitouwadge, Ontario. Photo by R.F. Sutton.

INTRODUCTION

This report reviews weed control in Canadian forestry, and is directed at foresters and lay readers, especially agriculturists. It aims to increase awareness of the silvicultural problems faced by foresters, the relative efficacy of options, and the problems peculiar to cost-risk-benefit analysis in forestry. Such analysis in relation to forest weed management is not assessed directly; the subject is treated elsewhere[1].

THE CANADIAN FOREST

Except for the Alpine and Arctic tundra and the grasslands, the natural vegetation of Canada is forest. Eight *forest regions* are commonly recognized: Boreal, Subalpine, Montane, Coast, Columbia, Deciduous, Great Lakes-St. Lawrence, and Acadian (Rowe 1972). Each forest region "is conceived as a major geographic belt or zone, characterized vegetationally by a broad uniformity both in physiognomy and in the composition of the dominant tree species" (ibid.).

A subdivision of a forest region is called a *forest section*, conceived as "a geographic area possessing an individuality which is expressed relative to other sections in a distinctive patterning of vegetation and of physiography" (ibid.). This is not to say that forest sections are homogeneous. They are not. Forest sections include all the variability, often substantial, that occurs within the boundaries of areas that are large because of the scale of mapping.

For some purposes, forest may be classified into *forest types* on the basis of the main tree species present, e.g., beech-maple, spruce-fir, and jack pine forest types (Spurr and Barnes 1980).

The forest may also be considered an interrelated assemblage of plants of various life forms (cf. Raunkiäer 1934, Mueller-Dombois and Ellenberg 1974) and animals living in a *biotic association*. The *forest association* is thus an assemblage of trees, shrubs, herbs, fungi, mammals, birds, arthropods, bacteria, etc., living together in a common environment (Spurr and Barnes 1980).

A forest community exists in, and interacts with, a physical environment provided by atmospheric, meteorologic, and edaphic factors. Together, a forest community and its habitat comprise an ecological system, or *ecosystem*. Taking in both the organic and inorganic aspects of the cyclic processes of life, the *forest ecosystem* is at the same time the most precise and the least comprehensible definition of the forest community (ibid.).

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[1] Sutton, R.F. and Payandeh, B. 1984. Forest vegetation management: opportunities for and constraints on cost-risk-benefit analysis. 54 p. typescript. Gov't. of Can., Can. For. Serv., Sault Ste. Marie, Ont. This paper is a contribution to the National Research Council of Canada Environmental Secretariat's Associate Committee on Scientific Criteria for Environmental Quality project: "A scientific evaluation of risk/cost/benefit assessment procedures for organic chemicals of concern in Canada (pesticides as a test case)".

The geographic nature of the concept was emphasized by Barnes (1982), who cited two clarifying descriptions:

> "...a topographic unit, a volume of land and air plus organic contents extended areally over a particular part of the earth's surface for a certain time (Rowe 1961)", and
>
> "...a perceivable unit of landscape, homogeneous both as to the form and structure of the land and as to the vegetation supported thereon (Rowe 1962)".

The classification of ecosystems is a complex undertaking based on specialized knowledge of vegetation, soil, geology, and climate (Barnes 1982).

The resources of ecosystems--space, energy, moisture, and nutrients--are limited. All organisms within an ecosystem must therefore compete for the resources they need for survival, growth, and reproduction (Lawrence and Walstad 1978). Trees, particularly as seedlings, are not exempt from the competitive struggle.

FOREST MANAGEMENT

Since time immemorial, mankind has sought and obtained many benefits from the forest (Satoo 1979), including fuel, timber, poles, pulp, cane, fiber, fabric, fagots, forage, flowers, fruits, fungi, flesh, fur, feathers, sap, syrup, sugar, gums, oils, resins, dyes, tannins, medicines, poisons, fertilizers, shelter, and amenity. The forest is able to provide benefits in perpetuity only if the demand does not exceed the natural rate of supply. Overexploitation depletes the resource. In extreme cases, the forest itself is destroyed. Vast areas of the world that formerly carried forest are now bare of trees, unintentionally denuded as a result of over-exploitation (Winters 1974). Other large-scale denudation has been caused by climatic change and agricultural practices. Benefits in excess of the natural rate of supply are obtainable only through the application of knowledgeable effort, i.e., management.

A useful representation of forest management in North America was made by Stone (1975), who viewed forest management as a spectrum of managerial purposes combined with the levels of skill and physical input involved, increasing from *remote wildlands* and *protected wild forest* through *exploited forest* and *regulated forest* to *domesticated forest*. Forest management may be applied at any affordable intensity needed to achieve the objectives of management.

In a regulated forest, adequate regeneration is assured, the number of trees per unit area and the species composition are controlled to some degree, and the productivity of the site is considered a fixed, inherent property. The exploited forest is utilized with little or no investment of effort other than that needed to extract the forest produce, regeneration being left entirely to nature.

The domesticated forest is exemplified by agroforestry (Zsuffa and Anderson 1981), the silvicultural extension of agriculture. A development of

the intensively regulated forest, the domesticated forest differs in receiving greater technological input, both physical and conceptual (Stone 1975). First, species or genotypes need not be those given by nature. They can be modified to exhibit more useful properties, to be more responsive to intensive culture, and to be less susceptible to pests. Second, the potential for productivity of a site is not accepted as a fixed quantity but is regarded as a variable that can be increased by soil modification or by a combination of soil modification and genotype response to it. Stone (ibid.) pointed out that, because of the heavy investment, regeneration of this forest after harvesting is not an issue; whatever needs doing is done. The current area of domesticated forest in Canada is very small, but it includes intensively managed plantations for short rotation, genetically superior poplar[2] (for producing pulpwood on marginal or submarginal farmland), and poplar farming (for producing wood fiber and animal fodder from closely spaced, short rotation coppice on farmland) (Zsuffa 1978), e.g., in southern Ontario (cf. Fayle et al. 1979).

At the extremes, the differences between the exploited forest and the regulated forest are clear, but the point of transition between them is not objectively determinable. It may be said that the Canadian forest industry is just approaching the threshold of regulated forestry but that exploitation remains the dominant characteristic: "the crux of the matter is that Canada's forests are being mined rather than farmed" (Sadler 1983). The transition to forest management amounts, in simplest terms, to "simultaneously orchestrating" two steps: harvesting the existing "old" forest over a period of time, to maintain the industry; and taking action to replace the old with a managed "new" forest that will thereafter be the source of industrial wood (Baskerville 1983).

The current reforestation effort is inadequate (Bonnor 1982). Morgenstern (1978), for instance, estimated that of the 251,000,000 ha of productive forest land in Canada, 750,000 ha are cut annually, and that nearly 200,000 ha of these do not regenerate adequately. On the questionable assumption that all planting and seeding conducted in Canada is 100% successful, if an allowance of 30% is made for successful natural regeneration, just over 50% of the area harvested is being regenerated (Brace and Golec 1982). The Science Council of Canada (Anon. 1983d) estimated that "each year some 200,000 to 400,000 ha of valuable forest are being added to this shameful waste". Furthermore, depletion by fire, insects and disease is greater than that by harvesting (Bonnor 1982). The cumulative area of inadequately stocked forest land was estimated by Reed et al. (1978) to be 30,000,000 ha, more than the total forest land area of Japan (25,000,000 ha) (Forster 1978), and more than twice that of France (14,600,000 ha) (Anon. 1982).

Canada's forests have been allowed to degenerate to a "dangerous point" in spite of the fact that they are essential to our social and economic well-being (Anon. 1983d). The forest industry provides employment for nearly 1,000,000 Canadians and contributes almost one-fifth of the nation's exports (Reed et al. 1978), which earn more foreign exchange than do oil, gas, minerals, agriculture, and fisheries combined.

---

[2] Botanical names of plants are given in the Appendix.

The need for intensified forest management (cf. Stone and Bengtson 1975) is only now beginning to be appreciated where it counts: "Industry and government are recognizing the need for better management of this renewable resource" (Anon. 1983d). Forestation efforts across Canada have increased substantially in recent years, rising from about 75,000 ha planted or seeded in 1965 to about 171,000 ha in 1979 (Cayford and Bickerstaff 1968, Hallett and Murray 1980). The proportion of this effort that results in successful forestation is debatable (cf. MacKinnon 1974, Heeney 1978), but there is no doubt that forest management is intensifying.

VEGETATION MANAGEMENT

Vegetation management is part of forest management. It is the principal means by which the forester diverts from weeds part of the limited resources of a given ecosystem in order to further the objectives of management. A weed is a plant pest, i.e. one that is noxious, destructive, or troublesome; it interferes, or is perceived as having the potential to interfere, with the attainment of the forest manager's objectives. Simply, a weed is a plant growing where it is not wanted.

In contrast with the farmer, who practises vegetation management with a view to sequestering to the crop all available resources within the highly artificial agronomic ecosystem, the forester normally does not attempt to eradicate weeds from the more natural forest ecosystem (Lawrence and Walstad 1978). Typically, on any given piece of ground, vegetation management treatments in agriculture are intensive and frequent, while those in forestry are less intensive and much less frequent: "one would find most, if not all, the plant and animal species in a managed forest that one would find in a 'wild' forest at the same...stage, albeit in a subordinate position" (Lawrence and Walstad 1978).

Unwanted vegetation causes problems in both forestry and farming, but whereas the agriculturist's main problem derives from annual plants and rhizomatous perennials, the silviculturist must contend not only with non-woody weeds but also with woody weeds (shrubs, trees, and sometimes vines).

Some of the factors that the silviculturist must take into account are as follows: woody weeds, usually deciduous, may become very large in terms of stem diameter, crown spread, and root spread; woody weeds may outlive the crop trees, reducing for very long periods the ability of forest land to produce goods and services; woody weeds are most competitive with crop trees 3 to 30 years old (Newton and Knight 1981); deciduous woody weeds also compete with small seedlings by smothering them with leaf fall; weeds may need to be controlled only once or twice in each crop cycle, generally 40 to 100 years, because once the crop trees become dominant they tend to remain so, just as dominant weeds tend to persist. Individuals of many species of dicotyledonous trees and shrubs are able to reproduce indefinitely by suckering or sprouting, but, with minor exceptions, the commercially valuable conifers are unable to regenerate vegetatively.

Large areas of inadequately stocked "backlog" forest land, though needing intensive vegetation management to bring them back into production, would thereafter require infrequent, less intensive treatment.

Encroachments on the forest land base (cf. Leitch 1983) will continue to reduce the area of forest land available for the managed production of industrial wood. On the one hand, this will tend to reduce the area of forest land that needs to be subjected to vegetation management. On the other hand, vegetation management on these industrial forest lands may need to be intensified.

NEED FOR VEGETATION MANAGEMENT IN FORESTRY

Where do weeds cause problems in forestry? Weeds interfere or have the potential for interfering with the following silvicultural and management activities (Cutler 1978, Witt 1978):

(a) production of planting stock in forest tree nurseries;

(b) preparation of sites for seeding or planting, either to reduce impediments to the movement of planters across the planting area, or to improve the performance of seeded or planted stock, or both;

(c) reduction of competition to crop trees during the establishment phase, i.e., before crown closure and before the crop has reached the "free-to-grow" stage (cf. Armson et al. 1980), when weeds may be woody, non-woody, or both;

(d) reduction of competition to crop trees after crown closure, generally the "release" of coniferous trees from overtopping deciduous woody weeds;

(e) other activities, both silvicultural and managerial, including thinning to reduce overcrowding among trees of the crop species, reduction of hazards other than those posed by weeds, maintenance of rights-of-way, roadside brush control for road safety, etc.

KINDS OF INTERFERENCE CAUSED BY WEEDS

Interference (cf. Zimdahl 1980) takes various forms: competition for resources needed for tree survival and growth; modification of soil conditions including soil temperature; smothering of seedlings by fallen leaves or snow-pressed non-woody vegetation; obscuration of sight lines and features of the landscape; physical impediment to movement across forest land and hence to activities such as site preparation and planting. These are mostly self evident, but what constitutes competition may need some elaboration.

Plants compete for light, moisture, nutrients, and, sometimes, space. They compete above ground and below ground. Root competition occurs whenever roots of different individual plants are sufficiently close together to modify the root environment to the detriment of either or both individuals (Sutton and Tinus 1983). Competition between overlapping root systems takes place long before the tops begin to shade one another (Pavlychenko and Harrington 1935). Allelopathic plants, by root exudation, create soil conditions unfavorable for other plants; even on trees, the effects can be lethal (Rice 1984).

POSSIBLE METHODS OF VEGETATION MANAGEMENT

Undesirable vegetation may be reduced by a wide variety of treatments. These include:

- *manual*, by hand alone, to uproot or break off weeds, or with hand tools, e.g. ax, Swede saw, machete, chain saw, brush saw, etc., to cut, notch, frill, etc.;

- *mechanical*, including bulldozing, blading, shearing, disking, chopping and rolling (with roller-choppers weighing as much as 20 tonnes), ripping, bedding, harrowing, plowing, etc. (Often, weed control is neither the sole nor the principal purpose of such treatments. Soil cultivation and disposal of post-harvest debris are commonly important objectives.);

- *prescribed burning* for vegetation management, mainly as a site preparation treatment to dispose of post-harvesting slash and brush in preparation for planting or seeding,

- *biological*, e.g., by using living organisms to stress weed hosts and so reduce the abundance and vigor of the weeds (In theory, specific weeds can be attacked by using specific insects or other arthropods, nematodes, or plant pathogens, but the practicability of this in the forest context is doubtful. General clearance of lesser vegetation (low weeds) has been achieved very effectively, albeit generally on a small scale, by using pigs and chickens, goats and geese.);

- *Systems based*, i.e., minimizing weed problems by intelligent anticipation and a systems approach (Especially on cutover sites, the extent of the weed problem is influenced greatly not only by the nature of the stand that was cut but also by the season and method of harvesting, the intensity of utilization, and the time that has been allowed to elapse between harvesting and the attempt to regenerate. Such factors are ignored in exploitation forestry, which strives to minimize the unit cost of extracted wood and maximize immediate profits. The result has been the virtually complete separation of harvesting and regeneration operations in Canadian forestry. This separation, together with the inadequacy of the regeneration effort by industry and governments alike, has produced weed problems on a vast scale (cf. Benzie et al. 1973). In regulated forestry, practices such as "advance site preparation" are applied to minimize the overall effort required to achieve management objectives. The Japanese, for instance, remove dwarf bamboo ("bamboo grass") from stands a year or two before the stands are harvested, to prevent the explosive post-harvest proliferation of the weed that would otherwise occur.);

- *chemical*, i.e., using phytotoxic chemicals to promote the objectives of management (To be useful as a herbicide, a chemical must be highly phytotoxic, effective against weeds at dosages of at most

a few kilograms per hectare, sometimes very much less [Crafts 1975]. Selective use of herbicides to treat weeds without harming crop trees may be achieved in several ways [Sutton 1967]).

CHOOSING THE METHOD OF VEGETATION CONTROL

Selection of a specific treatment depends on the nature of the job that is to be done, i.e., the kind and degree of change sought in the vegetation currently occupying a site. It depends, too, on what resources (time, labor, equipment, materials, and money) are available, and on any restrictions imposed by law or policy.

Determination of the job to be done implies a knowledge of the ecology of both crop and weeds. Rational choice of method implies a knowledge of the ecological possibilities and limitations of the available methods. Physical site factors such as terrain, exposure, soil type, erosion hazard, size of treatment area, and accessibility are also influential.

The choice of method will also be influenced by the size and urgency of the job to be done. Of the forest land in Canada that is currently sufficiently stocked with crop trees, very large areas require immediate treatment to release the crop from constraining weeds, which otherwise would stunt crop tree growth and threaten survival (Jones and Boateng 1983). The sheer size of the problem, difficulties of access, disinclination of labor to work in the forest, the dearth of labor in remote areas (cf. Ketcheson and Smyth 1977), and the reluctance of industry and governments to put enough money into forestation, are factors supporting the conclusion that Carrow (1983) reached with respect to forest weed management in New Brunswick: "While there are some alternatives for limited weed control, the magnitude and inaccessibility of most of the areas requiring tending makes aerial application of herbicides the only cost-effective technique." The conclusion applies equally to Canadian forestry in general. Cost effectiveness is especially critical in forestry because investments in site preparation and regeneration must be carried through the whole crop cycle and impose a greater risk than those made later (Hamel 1983). This is a major difference between forestry and agriculture.

Similarly, aerial application of herbicides is the logical means of controlling weeds on very large areas already dominated by weeds to such an extent that forestation with crop species is not feasible without site preparation (Hallett and Murray 1980). The presence of other constraints, however, would necessitate the use of other methods of site preparation in combination with or instead of the herbicide treatment.

Important considerations with respect to other methods include the drastic effect that some kinds of mechanical site preparation have on the forest floor and soil. For instance, a mechanical treatment that uproots most of the woody weeds will also remove topsoil, often with detrimental effects on crop trees subsequently planted there (cf. Peterson 1980). The effect on weeds of less drastic mechanical site preparation may be transitory, but the treatment may be necessary to secure access or, as inferred by Scheirl (1980), to relieve pressure from browsing. Mechanical site preparation may stimulate aspen to sucker (ibid.) and weed seeds to germinate.

Prescribed burning may control weeds to some degree, but it, too, can promote suckering, e.g., of aspen (Horton and Hopkins 1963), and is a major source of smoke pollution. In Canadian conditions, prescribed burning cannot be used against weeds when crop trees are present (Anon. 1983b). The reserves of nitrogen on a site may be greatly depleted by burning. Also, the use of prescribed burning is highly dependent on weather, fuel loading, and adequate ground supervision.

Manual methods (hand cleaning) must be used if it is necessary to control weeds where prescribed burning and/or herbicides cannot be used. These methods are highly selective and may be used with great precision, but they have many limitations, e.g., they cause resprouting or suckering from root or stump, often increasing the number of weed stems over the number present before treatment (Baskerville 1961). Furthermore, the effectiveness of manual methods may depend on sufficient retreatment, and crop trees may be damaged in the process (cf. Bernstein 1978). Two other major drawbacks are high cost and the scarcity of labor. Forster's (1978) observation that "the real limiting factor in carrying out silvicultural programs in the [Japanese] forest is the availability of forest workers" applies equally to much of Canada (cf. Ketcheson and Smyth 1977).

Comparisons between different methods of dealing with a weed problem are complicated because of the differences in the effects produced (Wittering 1974) in either weeds or crop or both.

HERBICIDES IN FORESTRY

Weeds contribute in various ways to forestry problems. Each problem must be analyzed individually to determine the best course of action over all.

Herbicides include widely diverse types of chemicals, ranging from simple inorganic substances through fairly sophisticated organic chemicals (Freed 1966, Witt 1978). Their effects on plants, and the manner in which these effects are produced, vary widely, from simple desiccation and contact action, as with inorganic salts and certain phenols, through the systemic effect of plant growth regulators, as with 2,4-D (Freed 1966).

On the basis of their acute oral toxicity to rats, herbicides as a class are much less toxic to mammals than insecticides. Apart from some of the inorganic salts, only the phenols, e.g., dinoseb, are highly toxic. The great majority of the organic herbicides have low mammalian toxicity.

The major effects of herbicides on non-target animals, fungi, and other organisms are generally limited to massive spills or grossly improper use: unlike field-use rates of insecticides, which may cause direct injury to non-target animals, "field-use rates of herbicides are not normally enough to produce effects on humans or [other] animals through primary or secondary intoxication" (Newton and Knight 1981). The overwhelming influence of herbicides on non-target organisms is through habitat change (Newton and Knight 1981).

One herbicide that can be directly toxic to forest fauna is dinoseb. As Newton and Knight (ibid.) pointed out, dinoseb is a general biocide, active as a

herbicide, fungicide, insecticide, and perhaps rodenticide, and therefore used only in preparation of sites for burning. Dinoseb has a short environmental life, is not translocated in plants, and has no systemic effect.

Witt (1978) listed 13 herbicides used in amounts greater than 100 lb (45 kg) by the United States Forest Service in fiscal year 1976: 2,4-D (55.4% of total weight of herbicide used), 2,4,5-T (20.5%), picloram (14.8%), MSMA (2.7%), dalapon (1.8%), simazine (1.7%), atrazine (1.1%), silvex (0.9%), 2,4-DP (0.6%), dicamba (0.5%), cacodyllic acid, amitrole, and glyphosate. The total weight of herbicides used was about 190,500 kg. In contrast, farmers in the United States in 1976 used about 178,700,000 kg (Anderson 1983). Although changes have since occurred, e.g., 2,4,5-T is no longer available for silvicultural purposes (though still registered for rice farming), and the use of hexazinone and triclopyr has increased, the general picture--the dominance of 2,4-D and the insignificance of the amount of herbicide used in forestry relative to that used in agriculture--remains unchanged.

Currently in Canada, only three herbicides, 2,4-D, 2,4,5-T, and glyphosate are federally registered for aerial application in forestry. However, forestry use of 2,4,5-T, has, by provincial policies based on political rather than biological considerations, for some years been banned in British Columbia, Saskatchewan, Ontario, and Quebec.

FOREST WEED CONTROL

The need for weed control in forestry arises in a variety of situations (Ayling and Graham 1978): forest tree nurseries, site preparation, tending of young crops during the establishment phase, tending of established crops, and others (e.g., rights-of-way, roadsides, firelines, and, in some cases, rangeland and pasture management).

Forest Tree Nurseries

Purpose

Planting stock is generally produced in forest tree nurseries as bareroot seedlings or transplants two or three years old or as containerized stock grown in individual containers for a year or less. Bareroot stock, which is raised in beds or lines, is subject to weed problems similar to those experienced by market garden crops but aggravated by the longer crop cycle needed to produce planting stock. The purpose of weed control in the forest tree nursery is identical to that of weed control in market gardening, viz., to permit the raising of a uniform, vigorous, healthy, and fully stocked crop that makes full use of the available resources. Weed control is a necessary and fundamental part of any program of nursery soil management (Armson and Sadreika 1979).

Determination of the Need for Treatment

Most weeds in forest tree nurseries grow much more rapidly than do tree seedlings. Weeds use up water and nutrients that are intended for crop trees and, if not removed while small, they shade and may physically distort crop plants (Armson and Sadreika 1979). Uncontrolled weeds may drastically reduce both survival rate and growth among crop trees. Just visualize a garden that has not been weeded for two or three years! Irrigation and fertilization, normal nursery practices, only compound the problem, the weeds benefiting from the additional resources, the crop suffering from the increased competition.

Options for Controlling Nursery Weeds

A. Manual: Prior to the development of effective herbicide treatments, the standard method of controlling weeds in nursery beds and within transplant lines was to pull the weeds by hand; hoeing was done between rows. Weeding by hand is tedious, uncomfortable and very expensive. Also, even if the weeds are removed while quite small, incidental damage to the crop by uprooting and other disturbance may be considerable. Not mentioned by Armson and Sadreika (1979), manual weeding alone is no longer a practical option, although it is still an important element in nursery weed control programs. Weed control is a major production cost (Owston and Abrahamson 1984).

Flame is used to some extent to control weeds in nurseries, and a variety of other methods, including electrical discharge (Rasmusson et al. 1979), solarization (Egley 1983, Horowitz et al. 1983), natural allelopathic chemicals (Shettel and Balke 1983), mycoherbicides (Templeton et al. 1979), and stimulated germination of weed seeds to facilitate subsequent control, are under investigation. The mainstays of weed control, however, apart from manual treatment, are mechanical and chemical.

B. Mechanical: Opportunities to control weeds in nurseries by mechanical means are limited mainly to fallow land. Hoeing between rows of trees, possibly combined with root-pruning of nursery stock, may be used to effect partial control. Mechanical control of weeds on broadcast-sown seedbeds is not feasible.

C. Chemical: Weeds in nurseries, other than those on fallow ground, are commonly controlled by herbicides, often with supplementary hand weeding. Although nursery weed control practices vary widely, evidence is plentiful that herbicides can effectively reduce weed populations and thereby reduce costs of hand weeding (Owston and Abrahamson 1984). In a Georgia nursery, for instance, treatment with diphenamid reduced the time needed to hand weed beds of 7-week-old seedlings of loblolly pine to 12-14% of the time needed to weed untreated beds (Dill and Carter 1973).

Some of the commonly used herbicides include mineral spirits, dacthal, simazine, diphenamid (Ayling and Graham 1978, Armson and Sadreika 1979), oxyfluorfen, and bifenox (Owston and Abrahamson 1984). In non-crop parts of nurseries, weeds may be controlled, at least in part, by herbicides, e.g., amino triazole (cf. Ayling and Graham 1978).

Diphenamid, dacthal, and simazine are used in pre-emergent applications. Diphenamid controls grasses and forbs, whereas woody plants are generally tolerant. Dacthal is effective against crab-grass and other annual grasses and a broad range of forbs, while woody plants are mostly tolerant; it has little or no post-emergent effect on most crops and weeds (Armson and Sadreika 1979). Simazine will control a wide spectrum of weeds, but some species are resistant; it has been used extensively in transplant lines (van den Driessche 1969) and is also effective against many weeds in walnut seedbeds. Oxyfluorfen and bifenox can control a wide spectrum of broadleaved and grass species. Oxyfluorfen is a contact herbicide effective in both pre- and post-emergence periods; bifenox, an effective pre-emergence herbicide, also has post-emergence capability on weeds up to about 5 cm tall (Owston and Abrahamson 1984).

Post-emergent application of mineral spirits of the varsol type (preferably with an aromatic hydrocarbon content of close to 20%) is effective against a broad spectrum of weeds while the weeds are very small; pines and spruces are relatively tolerant, but larch and white cedar are susceptible to mineral spirits (Armson and Sadreika 1979).

Site Preparation

Purpose

Site preparation is the treatment of a site prior to seeding or planting in order to facilitate the regeneration of that site by the chosen method (Sutton and Tinus 1983). Site preparation may be needed to effect any of the following purposes singly or in combination: reduction or redistribution of slash (for access, reduction of fire hazard, or sanitation); reduction of competition from residual vegetation; soil cultivation; exposure of mineral soil; drainage; and the facilitation of regeneration operations to improve quality and reduce cost.

Determination of the Need for Treatment

Experience has shown that, in much of Canada, attempts to regenerate cutover land are rarely successful unless sites are prepared, by removing or reducing one or more constraining features. Seeding or planting commonly fails in the absence of site preparation. "To establish most species of trees, some form of site preparation is essential" (Heidmann 1984).

When weeds constitute a major constraint, their effect may be markedly reduced by various treatments. Mullin (1972), for instance, found that, 10 years after planting into untreated sod, red pine seedlings averaged 31% survival and 110 cm in total height, whereas similar stock planted into scalped soil had a survival rate of 59% and a mean total height of 186 cm, even though scalping may not have been the best site preparation treatment. For red pine transplants in the same study, the comparable values were 27% survival and 88 cm total height in untreated sod, and 85% and 179 cm in scalped sod. Millions of trees have disappeared without trace after having been planted without prior site preparation; millions more have disappeared after planting on inappropriately prepared sites. For hardwoods, too, site preparation and weed control

"are essential to the successful establishment" of plantations on abandoned agricultural land in southern Ontario (von Althen 1979).

Vegetation may qualify as weed growth on any or all of several counts, including: competition for moisture, nutrients, and light; physical obstruction; and food and cover for animal pests. With respect to the latter, the habitats of animal pests can be changed by selectively favoring or discouraging appropriate components of the vegetation, thereby altering the pest-carrying capacity of a site (cf. Keith et al. 1959, von Althen 1983).

Options for Weed Control for Site Preparation

A. Manual: Non-woody weeds may be scalped off in patches or strips to expose mineral soil for seeding or planting. Such treatment, applied manually or by machine, commonly allows old-field sites to be regenerated successfully (cf. Mullin 1972), whereas without weed control, failure is almost certain. In many circumstances, however, scalping does not benefit survival (Lawrence and Walstad 1978), and may be detrimental (McMinn 1983) especially on heavy soils in consequence of ponding and frost heaving.

Woody weeds may be controlled manually with hand tools of various kinds, but in practice, except on a small scale, the application of manual weed control is severely limited by the reluctance or insufficient numbers of laborers to undertake the work (cf. Ketcheson and Smyth 1977, Anon. 1983b), which is gruelling and hazardous (Lawrence and Walstad 1978). Furthermore, manual treatment is generally less effective than chemical or pyrogenic treatment because of resprouting and is generally much more expensive. The option is generally considered impracticable (cf. Carter et al. 1978).

B. Mechanical: Mechanical methods include bulldozing, shearing, crushing, chopping, plowing, disking, bedding, etc. Such treatments effect initial control of weeds. They also facilitate subsequent planting or seeding by rendering slash less of an impediment. The effect produced by any given treatment is highly site-specific; and on any given site, the effect produced by any given treatment is specific to site condition. The duration of the weed control resulting from mechanical treatment may be short or long, depending largely on the severity of soil disturbance.

The effects of mechanical site preparation on the soil and vegetation can vary enormously depending on a complex of factors, including the type and class of machine and equipment and how they are used, treatment intensity, topography, condition of the site at time of treatment, operator competence, and the quality of supervision. Any single specified treatment may produce a very wide range of effects in both weeds and soil.

Complete cultivation has been an effective site preparation treatment for establishing stands of trees, including southern Ontario hardwoods (von Althen 1979), at least on sites initially dominated by broadleaved weeds. But even intensive plowing in early summer followed by repeated disking during the summer and autumn fails to control all weeds, e.g. quackgrass (ibid.). Some of

the intensive mechanical site preparation used for southern pines in the southeastern United States produces greater crop growth responses than have been obtained with allowable rates of 2,4,5-T (Carter et al. 1978). In one study in the southeastern United States it was found that complete cultivation (double disking) gave good control of weeds and, five years after planting, produced in loblolly pine a volume increment 440% greater than that of trees planted without site preparation (Schultz 1974).

In operational practice in Canada, except for small-scale site preparation for the establishment of high-value hardwoods and other special purpose plantings, complete cultivation is precluded by edaphic, topographic, and economic constraints. A problem of partial treatment is that any given treatment may produce dramatically different effects of site preparation depending on the size and shape of the part(s) of the area treated in comparison with those of the area left untreated.

Nevertheless, in the north-central interior of British Columbia, for instance, McMinn (1981) found scalping by means of a bulldozer blade to be an operationally effective method of exposing mineral soil and controlling competing vegetation, giving biologically acceptable results with respect to crop trees on medium-textured to moderately coarse-textured soils that do not impede root growth of crop trees. Also in north-central interior British Columbia, Dobbs (1976) found that blade scalping on a silty clay loam site improved third-year survival and growth in a variety of stock classes in both lodgepole pine and white spruce (Table 1).

Table 1. Survival and growth (overall means for six stock classes) of lodgepole pine and white spruce, 3 years after outplanting, as affected by blade scalping site preparation (after Dobbs 1976).

Scalping	Survival (%)	Mean growth				
		Total height (cm)	Height increment (cm)	Stem diameter (mm)	Dry mass	
					Shoot (g)	Root (g)
		lodgepole pine				
No	88	50	39	10	50	14
Yes	96	57	46	12	77	21
		white spruce				
No	87	33	20	6	15	6
Yes	94	37	24	6	19	9

Within species within columns, all differences are significant (P 0.01).

Mechanical site preparation is not without problems. Treatment that removes the relatively fertile surface soil layer, leaving relatively infertile or otherwise inhospitable soil, although it may promote germination, may stunt the growth of naturally regenerated or introduced crop trees. LeBarron (1944), for instance, found that while the removal of the lesser vegetation and the organic forest floor layer increased numbers of jack pine and black spruce seedlings, the seedlings were unthrifty and showed symptoms of nutrient deficiency. Also, frost-heaving problems are aggravated in mineral soil that has been exposed by some kinds of site preparation (cf. Heidmann 1976). Ponding and drainage problems may be created, and soil disturbance increases the likelihood of soil erosion, which may be devastating for young crop trees even when the amount of erosion is small.

Some weed problems are exacerbated rather than ameliorated by mechanical site preparation (Anon. 1983b). A case in point is the stimulation of suckering from the roots of aspen; in addition, weed seeds that have been lying dormant in the soil may be stimulated to germinate.

Mechanical site preparation suffered greatly from the unprecedented increases in oil prices that began in the early 1970s. Before the end of the decade, Dierauf (1978) reported that the cost of bulldozing and chopping as site preparation in Virginia had increased five times more than had the cost of aerial herbicide treatment.

Mechanical site preparation may be used in combination with prior herbicide treatment, as with "brown and crush" techniques (cf. Gratkowski et al. 1973, Newton and Knight 1981).

C. Fire: Vast areas of natural stands of forest trees in Canada owe their existence to natural site preparation by fire. Prescribed burning can achieve similar results.

Whether or not a given site needs to be treated to alleviate constraints in addition to those posed by weeds, fire may be used with other forms of treatment. "Brown and burn" techniques (cf. Hurley and Taylor 1974) are well developed in parts of the United States (cf. Carter et al. 1978) and elsewhere.

An advantage of fire over mechanical methods of site preparation is that, although some nitrogen may be lost, nutrients released by the burning are available to the new crop (Chandler et al. 1983). Also, fire disturbs the soil less than do mechanical methods in general because it does not involve the use of heavy equipment, and thereby avoids the dangers of both accelerated soil erosion and soil compaction. The main silvicultural disadvantage of fire in site preparation is that the effects are not uniform across the area treated. Material more than 5 cm or so in diameter is seldom completely incinerated, and, while residual large logs offer shade and a favorable microclimate for crop trees if the area is to be hand planted, residuals may severely limit or even preclude further treatment by machine (ibid.).

After prescribed burning or natural fire, some components of the vegetation, including shrubs such as pin cherry (Likens et al. 1978), may regrow vigorously.

Though closely resembling a natural process, prescribed burning is becoming increasingly restricted by legislated constraints, both in Scandinavia (Viro 1969) and in North America (Dierauf 1978, Lawrence and Walstad 1978). Other drawbacks have been discussed under **"CHOOSING THE METHOD OF VEGETATION CONTROL"**.

D. Chemical: Effective site preparation may be obtained with herbicides alone "only when the [weed] vegetation is very susceptible, when the slash [residue from the previous harvest] density is low, when [the amount of] litter is light enough to permit seeding, or the brush... sparse enough to allow planting [to be done] at reasonable cost" (Stewart 1978). Chemical site preparation alone has either or both of two objectives: reduction of weed competition, and alteration of animal pest habitats.

Herbicides may be used effectively in site preparation to control virtually any type of vegetation, including grasses, ferns, forbs, vines, shrubs, and trees. For site preparation, herbicides are used in ways that maximize their effectiveness, selectivity being inconsequential in situations in which there are too few desirable trees to warrant saving them (Newton and Knight 1981). Where crop trees must be conserved, the selective capabilities of the herbicide tool (cf. Sutton 1967) must be employed.

Herbicides are useful for carrying out site preparation in unstocked or under-stocked portions of plantations or natural stands. The use of fire is impracticable in these situations, and mechanical equipment, in passing through stocked portions of the area, would inevitably damage crop trees.

The chemical method of site preparation leaves the forest floor essentially undisturbed, a poor seedbed for most seeds. This largely avoids what Newton and Knight (1981) have called "surprise weed problems".

A disadvantage of using herbicides alone for site preparation is that the treatment leaves a residue of standing dead or dying vegetation, which may impede planting or seeding and may also shelter animal pests and allow them to proliferate.

A further disadvantage occurs when a minor component of a weed population is resistant to a herbicide treatment that is effective against the other components. This minor component may then develop into a major problem. A case in point is the strong development of raspberry from insignificance in the flora of some boreal forest stands to dominance after 2,4-D has been used against other components of the vegetation (Sutton 1958). In this instance, the use of 2,4,5-T would solve the initial problem without creating the second.

The Canadian forest manager is restricted in the herbicides he may use for site preparation. A much wider range of herbicides may be used in the United States (Table 2).

Table 2. Herbicides used in site preparation in the United States (after Newton and Knight 1981).

Vegetation type	Herbicide	Method of application	Comments
Grasses and forbs	dalapon	aerial or ground	delay planting 2 weeks
	atrazine	aerial or ground	
	hexazinone	aerial or ground	used in Oregon, Washington only
	glyphosate	aerial or ground	used in Maine, Oregon Vermont, Washington only
Broadleaved forbs only	2,4-D	aerial or ground	
Ferns	asulam	aerial or ground	versus bracken fern
	glyphosate	aerial or ground	versus bracken fern
	dicamba	ground	versus sword fern
Shrubs, coniferous	2,4-D, 2,4,5-T[a] Silvex[a], triclopyr ester	aerial or ground	
	picloram + 2,4-D	aerial or ground	delay planting for 6 months
Shrubs, deciduous	dinoseb	aerial	used for preburn desiccation in Washington, Oregon
	2,4-D, 2,4,5-T[a] Silvex, picloram + 2,4-D, dicamba + 2,4-D, glyphosate	aerial or ground	
Trees, deciduous	2,4-D, 2,4,5-T[a] Silvex[a], triclopyr	aerial or ground	no geographical restriction
	picloram	aerial or ground	delay planting for 6 months
	fosamine	aerial or ground	used in Pacific Northwest only.
	glyphosate	aerial or ground	

[a] "Products suspended 3/1/79, pending cancellation proceedings. Technical evidence appears to support continued registration for forestry purposes" (Newton and Knight 1981). Registration of 2,4,5-T has now been cancelled.

Crop Establishment

Purpose

Weed problems do not cease with the planting or seeding of site-prepared ground. New or resprouting growth is often a greater competitive threat to young crop trees than is the damaged vegetation remaining after site preparation (Greaves 1978). The juvenile growth of weeds commonly outpaces that of young crop trees. If uncontrolled, weeds may rapidly become dominant. Millions of crop trees (cf. MacKinnon 1974, Miller 1977) have died through lack of tending during the establishment phase. The problem is particularly severe on sites of above-average fertility. The purpose of weed control during the establishment phase, therefore, is to secure survival of crop trees and bring them as quickly as possible to the "free-to-grow" state, i.e., an adequately stocked stand of crop trees that average 1 m or more in total height and are "essentially free from competing vegetation" (Armson et al. 1980).

With good site preparation and an appropriate regeneration method properly applied, and without any exceptionally severe stress (from whatever cause, including weather, insects, disease, or weeds), the establishment period in Canada is rarely less than four years, even with pines; with spruces, which typically have slower initial growth rates than do pines, the establishment period may well be eight years or more.

Determination of the Need for Treatment

During the establishment period, weeds may cause stress to crop trees through competition, smothering, and harboring of pests. Of these effects, the least obvious is competition for nutrients on xeric, infertile sites, where control of quite sparse vegetation has produced strong growth responses in young white spruce outplants (Sutton 1975).

The need for treatment may be determined on the basis of visual inspections of the crop tree condition and of the relative growth rates of crop trees and weeds. Factors of significance include height, height increment, stem diameter, stem diameter increment, leaf size, leaf number, leaf retentivity, bud size, foliage color, nutrient status of crop trees, and the proximity of crop trees to weeds that might fall or be pressed by snow onto them.

Options for Controlling Weeds during Establishment

An important consideration, sometimes lost sight of, is that, no matter how effective it is in controlling weeds, a treatment is useless unless it is applied while the crop trees still have the vigor to respond to the increased resources made available. The options for effecting such treatment are fewer than those for site preparation because of the presence of crop trees. Though sometimes lumped in with "release", such treatment is more appropriately termed "cleaning" (or at least "pre-release") in order to avoid connotations of captivity. The objective here is to *maintain* crop tree vigor.

A. Manual: Hand-cleaning of young plantations, several times a year in some circumstances, was a normal part of classical silvicultural practice. The method is effective when carried out early and often enough, but it is now economically unfeasible for general application. For special purposes on a small scale, however, hand-cleaning is still a useful supplement (cf. Miller 1977, Nolan 1977).

B. Mechanical: Opportunities for mechanized cleaning in young crops are limited to a few special situations (cf. Brittain 1983).

C. Chemical: Chemical cleaning is virtually identical in principle with chemical release, and similar considerations apply to both. They will be discussed together in the section on **"Release of Established Crop"**.

Release of Established Crop

Purpose

Release is the removal or reduction of interference by weeds with the performance of established crop trees, i.e., crop trees of any age after establishment. In the post-establishment stage, weeds do not pose any immediate danger to the survival of crop trees. Newton and Knight (1981) defined release as the selective control of weeds in a stand of crop trees. Commonly in Canada, crop trees are coniferous, the weeds deciduous hardwoods.

Determination of the Need for Treatment

The existence of a problem and the assessment of the need for treatment are usually decided on the basis of visual inspection by the forest manager, who takes particular note of the current trends in height and diameter increments and crown development in both crop and weed trees.

Subsurface competition for moisture and/or nutrients may be a greater constraint than is aboveground competition for light and space, but, since it is difficult to visualize or measure, it is seldom considered sufficiently.

There is no doubt that, in many circumstances, the development, and sometimes the eventual survival, of established crop trees is jeopardized by weeds, and this is especially true in forest stands occupying sites of greater than average fertility.

In any given case, the size of the problem and the need for release depend on both the situation and the objectives of management. The current situation is the outcome of all that has preceded it. In particular, the degree of interference and the disposition of the crop trees are functions of past harvesting practice, of the method, timing, and intensity of site preparation and, in the case of plantations, of the quality of planting stock and of

planting. The need for release can be minimized by appropriate site preparation and vice versa. Ideally, release treatment should be applied just before crop trees would otherwise begin to lose growth momentum. Only if crop trees are vigorous can they make effective use of resources diverted from the weeds.

Options for Effecting Release

A. Manual: Hand tools can be used to remove woody weeds that threaten crop trees. This was the classical silvicultural method, fully efficacious if repeated often enough. Selection and spacing of crop trees can be carried out conveniently as an integral part of manual release treatment (Buckman and Lundgren 1962, Anon. 1978).

For 50 years, manual release has received little attention experimentally and has generally been regarded as economically unfeasible, except for small-scale operations (Andres et al. 1978). On the evidence provided by release cuttings reported by Young and Eyre (1937) and Buckman and Lundgren (1962), however, manual release could be "an excellent investment" under some circumstances. Buckman and Lundgren (1962) noted that release, though effective in the three studies reported, probably would have been cheaper and more effective had it been done earlier in the life of the stands; they also commented that herbicides, applied by hand in frills or girdles, or sprayed from the air, "would be used in many situations today." The relative economic feasibility and efficacy of herbicide and manual treatments were not discussed.

Andres et al. (1978) reported that an organized group of volunteer forest workers in California, representing the public interest organization *Group for Organic Alternatives to Toxic Sprays* "is showing that conifer release...may under many circumstances also be carried out with intensive, skilled manual labor". That release may be effected by manual cutting is not, however, in dispute. Questions that are more difficult to answer are: What is the cost of manual release? Are there enough laborers able and willing to do the job, especially in remote, lightly populated areas such as the boreal forest? How serious are the economic implications of the shorter period of effectiveness with manual treatment in comparison with chemical treatment?

In the studies reported by Buckman and Lundgren (1962), the youngest of the three stands at the time of release was 19-year-old red pine, the oldest 35-year-old white pine and red pine; release treatment was applied once only. Buckman and Lundgren, after speculating on how much more favorable the response might have been had the treatment been applied at an earlier age, observed that two or more treatments might then have been required because of sprouting or suckering of hardwoods.

B. Herbicide applied from the ground: Herbicides can be applied manually to treat woody weeds with precision comparable to that possible with hand cutting tools. For instance, tree injectors are used to introduce metered doses of herbicide into individual trees (Wittering 1974). Considerable precision is also possible with hand-operated backpack sprayers, but this is not true of mistblowers, which also accentuate problems associated with the drift of herbicide onto non-target vege-

tation. The use of herbicide delivery systems mounted on wheeled or tracked vehicles is limited by the presence of crop trees as well as by any other constraints, vegetational, edaphic, or topographic.

The period of effectiveness may be many times longer after herbicide than after cutting treatment, systemic effects being obtainable with the former (Sutton 1958), sprouting commonly occurring after the latter. A further advantage of herbicide treatment over cutting is that woody weeds succumbing to herbicide do not have to find a place on the ground; losses to crop tree seedlings by damage or burial under slash, 31% in one test (Bernstein 1978), are thereby avoided. Also, the gradual reduction of a canopy after herbicide treatment of weed trees is often more beneficial silviculturally than is sudden exposure.

C. Herbicide applied from the air: Aerial application of herbicide is an effective, efficient, selective silvicultural tool for releasing coniferous crop trees from hardwood weeds. The precision of the method is obviously less than that possible with some ground applications, but the technology of aerial application has advanced to the point at which spray patterns can be constrained to produce, with each nozzle on an airborne boom, an individual, narrow, sharply defined strip of treated vegetation.

Aerial application is widely regarded as the only "workable means" of using herbicides to release conifer crop trees from hardwood competition (cf. Hallett and Murray 1980). Carter et al. (1978) have noted that in the Pacific northwest and southern pine forest areas of the United States, aerial application of 2,4,5-T has proved to be the *"only"* practical treatment for releasing conifers from severe brush competition (cf. Gratkowski 1975, Walstad 1976). After an exhaustive and well reasoned evaluation of vegetation management tools in the context of forestry in Washington State, Newton and Dost[3] concluded that "aerial application of herbicides is associated with a lower risk to both site productivity and human health than any alternative".

Several herbicides are registered in the United States for aerial application for conifer release (Newton and Knight 1981, Hamel 1983). In Canada, only 2,4-D, 2,4,5-T, and glyphosate are registered federally for this purpose; and for political reasons the provinces of British Columbia, Saskatchewan, Ontario and Quebec have for several years suspended this use of 2,4,5-T, notwithstanding the large body of evidence and informed opinion testifying to the safety of the phenoxy herbicides in silviculture (cf. Walstad and Dost 1984).

In spite of some speculation to the contrary (cf. Westing 1979) and legitimate concern for environmental quality (cf. Kearney 1977), more than 20 exhaustive reviews commissioned by governments and institutions in several countries (Dost 1978, Footnote 4) have concluded that 2,4,5-T may be used safely

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[3] Newton, M. and Dost, F.N. 1984. Biological and physical effects of forest vegetation management. Final report. Submitted to Wash. Dep. Nat. Resour., Olympia, Wash. 423 p.

[4] Dost, F.N. 1983. Health implications of forestry herbicides--the public problem. Mimeogr. notes produced for two seminars organized by Assoc. B.C. Prof. For. and for a television program. Oregon State Univ. (unpubl.)

for registered silvicultural (and agricultural) purposes. None has reached a contrary conclusion. Excerpts from two or three of these reviews will illustrate the weight of opinion.

In a written reply to a question in the British House of Commons on 19 July 1978, Mr. Gavin Strang, M.P., Parliamentary Secretary, Ministry of Agriculture, Fisheries and Food said:

> "...the advice from [the Advisory Committee on Pesticides] is entirely reassuring. It has again reaffirmed that the [2,4,5-T] products concerned can safely be used in the recommended way for the recommended [including silvicultural] purposes; nor has it discerned any grounds for modifying the conclusions it reached over a year ago that no new and unacceptable risks attend upon the burning of material treated with these products." Further, Strang "noted with interest that the Australian Government's National Health and Medical Research Council, after considering allegations of the kind that have recently been revived in this country, reported last month in much the same sense" (Anon. 1979).

The Ministry's Press Notice No. 244 included the following:

> "All formulations of 2,4,5-T used in the United Kingdom have been cleared under the Government's Pesticides Safety Precautions Scheme. Under this Scheme, clearance for marketing a product is not given unless the Government, advised by the Advisory Committee on Pesticides, is satisfied that the product can be used without risk to humans, livestock or domestic animals, and with minimal risk to wildlife. There is also provision for the review of clearance should new evidence relating to a chemical become available. 2,4,5-T has been reviewed eight times since 1970."

The Herbicide Committee of the Inverness-Victoria Medical Society, Nova Scotia (Anon. 1983a) reviewed the medical literature on 2,4-D and 2,4,5-T and "found no evidence that the general population will suffer any harm from a forestry spray program" using these herbicides.

Similarly, the Hon. Mr. Justice Nunn (1983) of the Trial Division, Supreme Court of Nova Scotia, in his 182-page decision in the case (SN. No. 02555) of Victoria Palmer et al. versus Nova Scotia Forest Industries noted that "the evidence went far beyond the particular substances involved [viz. 2,4-D as Esteron 600, 2,4,5-T with its contaminant TCDD, and a mixture of 2,4-D and 2,4,5-T as Esteron 3-3E] and related to all the phenoxy herbicides and their derivatives." Justice Nunn felt it incumbent on him "to set forth this detail of fact" and his own observations so as to make clear that all the evidence available had been presented by the parties. He concluded that, "based on this evidence, fully weighed and considered, this court is of the opinion that these spraying operations can be carried out in safety and without risk to the health of the citizens of this province."

CONVERSION

If crop trees are introduced into an established stand of weed trees for the purpose of silvicultural conversion, i.e., a change from one, or one set of, tree species to another, weed competition must be weakened enough to enable crop trees to survive and develop satisfactorily. Two fundamentally different approaches are possible.

One approach is to remove the existing vegetation, root systems included, and then plant the desired crop trees. The silvicultural effectiveness of such treatment, which at the extreme creates bare "ball-parked" ground, depends greatly on soil factors and crop tree silvics. In effect, such treatment is a drastic form of site preparation.

The other approach is to divert part of the growth resources of the site from weeds to crop trees. Ideally, the released resources are fully utilized by the crop; if resources are released at rates in excess of the ability of crop trees to use them, no benefit from the surplus accrues to the crop, and the site may be impoverished (Sutton 1970). Herbicide treatment is not the only way of effecting such diversion of growth resources, but, other than on an extremely small scale, it is the only feasible way. The silvicultural effectiveness and ecological benignity of the method are illustrated by a study reported by Sutton (in preparation).

Once the introduced crop trees have become established, any necessary subsequent weed control would be effected by release treatment.

EFFICACY

Efficacy is the capacity to achieve the object intended. Glossaries of weed science terms by Newton and Knight (1981), the Weed Science Society of America (Beste 1983), Anderson (1983), and the unpublished glossary (1980) prepared by the Nomenclature Subcommittee, Canada Expert Committee on Weeds, do not list the term. Efficacy is commonly assumed to refer to the capacity of a herbicide to affect weeds deleteriously. This has etymological logic on its side, but surely *crop* response, not *weed* response, is the appropriate measure of efficacy if the intended objective is to promote the performance of crop trees.

Because the question of efficacy must take account of purpose, it is important to use terminology that reflects this. Therefore, I propose that the capacity of a herbicide to cause direct phytotoxic effects in weeds be termed *herbicidal efficacy*, and that the capacity of a herbicide indirectly to promote positive growth responses in crop trees be termed *silvicultural efficacy*. The relationship between herbicidal efficacy and silvicultural efficacy may be strong or weak, positive or negative, depending on the ecological skill of the silviculturist in identifying the weed component of a silvicultural problem and devising a treatment to overcome that constraint.

Silvicultural efficacy, therefore, is the silvicultural benefit derived from a treatment, i.e., performance of a treated crop *minus* performance of an untreated crop.

In further discussion here, we will therefore consider some silvicultural operations individually. Forest tree nursery stock production will be excluded because, important as weed control is to the production of planting stock, nursery weed control is an insignificant part of the overall forest weed problem. Similarly, conversion is excluded because of its lack of prominence in current silvicultural practice in Canada.

Site Preparation

Herbicidal efficacy is the usual basis for evaluating chemical site preparation treatment. The effect of a herbicide treatment on weeds is reasonably obvious, at least with respect to the short-term response of above-ground tissues. This is the effect that is of prime interest to the silviculturist engaged in site preparation.

A more sophisticated evaluation would use a systems approach and also take account of residual effects on subsequently introduced crop trees. A silviculturist has no logical basis for applying treatment of unknown silvicultural efficacy.

Residual effects are extremely difficult to determine. Other factors, such as planting stock potential, planting quality, and the residual effects of site preparation treatment addressed to constraints other than those presented by weeds, confound the determination of silvicultural efficacy. Nevertheless, in many situations, site preparation to remove or diminish a weed constraint is essential if the regeneration attempt is to stand any chance of success. Two examples will suffice to prove this point. The survival rates of black cherry seedlings 30 months after planting in dense New York fern and hay-scented fern were several times greater in plots that had been site prepared with herbicides than in untreated plots (Table 3).

Table 3. Survival (%) of black cherry seedlings 30 months after planting on a hay-scented fern and New York fern site in Pennsylvania, as influenced by chemical site preparation (after Horsley 1981).

Application rate (kg/ha)	Bromacil	Glyphosate	Picloram	Hexazinone
	- - - - - - - - - - - - Survival (%) - - - - - - - - - - - -			
0	18a	19a	19a	12a
3.8	79b	88b	56b	88b
6.7	83b	92b	88c	94b
13.4	75b	92b	75c	81b

Means followed by the same letter do not differ significantly (P 0.05) according to Duncan's new multiple range test.

Also, first-year survival of white spruce outplanted in dense grass with and without weed control was 94% and 22%, respectively (Sutton 1975).

Not all weed control effected by site preparation is beneficial. White spruce was severely heaved by frost, and survival was "greatly reduced" by chemical site preparation that eliminated the ground vegetation (von Althen 1970). With white spruce, too, on some sites, the beneficial nurse effect of "weeds" is important.

Tending (Selective Control of Weeds in the Presence of Crop Trees)

Of the several glossaries of weed science terms that I have seen, only that by Newton and Knight (1981) includes a definition of the term "release": "selective control of undesirable vegetation in the presence of desirable species". Most such glossaries are agriculturally oriented. Elsewhere, various meanings have been attributed to the related silvicultural terms "weeding" and "cleaning".

In essence, however, two distinctly silvicultural purposes may be served by weed treatment in the presence of crop trees: maintenance of crop vigor by preventive treatment of weeds before crop vigor is compromised, and rescue of suppressed crop trees failing in competition with weeds. As defined by Newton and Knight (1981), the term "release" includes both kinds of treatment. However, since "release" commonly connotes "rescue", a useful differentiation may be made between "prerelease" treatment for maintaining vigor ("weeding" during the establishment phase, in British Forestry Commission usage), and "release" treatment undertaken to rescue established but declining crop trees.

Prerelease

The silvicultural efficacy of prerelease treatment is clearly inferred from indirect evidence. For example, of the coniferous bare-root stock planted in northern Ontario from 1966 to 1968, 40% died within five years (MacKinnon 1974). Miller (1977) identified weeds as a major cause.

In North America generally, losses among outplanted stock from lack of tending have been enormous. Losses include not only increased mortality rates but also decreased growth rates among survivors and deferment of the harvest. However, the results achieved by the limited amount of prerelease treatment that has been applied have been difficult to document (Miller 1977).

Release

Herbicidal efficacy and silvicultural efficacy do not necessarily coincide with respect to the release of crop trees by herbicidal treatment of associated vegetation. Equivalence is probably safe to assume only when two conditions are met: the crop trees must be able to respond positively to the changes effected by the treatment; and the biological changes effected must selectively favor the crop trees in their current condition and distribution.

In general, the release of established crop trees is a more straightforward operation than are treatments applied during the establishment phase, both the immediate results and longer-term consequences of treatments being more predictable.

COST-RISK-BENEFIT EVALUATION; PROBLEMS PECULIAR TO FORESTRY

Some of the difficulties inherent in determining costs, risks, and benefits of weed control by various methods are aggravated in forestry situations. The complications include forest ecosystem heterogeneity, response time, lack of equivalence between options, proportion of landscape treated, and frequency of treatment.

Forest Ecosystem Heterogeneity

Except in some old-field situations, forest ecosystems are heterogeneous, often highly so, in marked contrast with the generally homogeneous agricultural ecosystem. The heterogeneity has major consequences. Variation in the non-vegetative (and also some of the vegetative) components of a forest ecosystem influences both the range and the effectiveness of the weed control options open to the forest manager; variation in trafficability and traversability has particular implications for mechanized weed control.

Heterogeneity also poses the problem of devising a weed control treatment that will achieve the desired overall result. In this regard, manual techniques, if available, have advantages over others.

Another problem is that both the determination of the overall effect of a treatment and the detection of differences between treatments are much more difficult in the heterogeneous than in the homogeneous ecosystem. The greater the variability, the greater the uncertainty attached to any mean value, difference, etc.

Response Time

Whereas in agriculture full evaluation (including crop response) of a weed control treatment is usually possible at the end of one growing season, comparable evaluation of a forest weed control treatment is not possible in less than the length of the rotation. To obtain any useful information, at least three years of observations are necessary. During this response period, other factors, e.g., unseasonal frost, drought, rodent epidemic, insect infestation, etc., interact with the weed control treatment, adding to the experimental error.

Several factors affect response time. Any amelioration effected by a forest weed control treatment is commonly gradual, and there may be more than one component (each with its own rate, intensity, and duration of effect) contributing to the amelioration; there may also be a negative component, e.g., when a beneficial nurse effect is reduced by the weed control treatment.

Furthermore, crop trees that are small or in poor condition are able to respond sluggishly at best to any amelioration of site factors. All too often, forest weed control treatment is delayed until a pronounced decline in the vigor of the crop trees begins to occasion alarm. Even if crop trees are still able to respond to ameliorated conditions, the response during the first few years is usually small and often obscured by uncontrolled variation, or else it occurs undetected in the root system.

Lack of Equivalence among Options

Forest weed control treatment options are not equivalent to one another in all respects. Even though each may effect a given degree of weed control, the impact on the ecosystem, including the effect on the weeds beyond the immediate effect achieved by the treatment, may be very different in the various options. Incidental effects on sprouting, suckering, soil moisture, soil temperature, soil nutrient availability, insects, disease, and traversability vary so much among options that evaluations based solely on degree of immediate weed control are insufficient. Options need to be evaluated on a systems basis, but the data for this are generally unavailable.

Proportion of a Landscape Treated

A very small proportion of any forest landscape is treated in any given year. With regard to chemical weed control in Canada, for every hectare of forest treated in a given year, 400 ha of farm are treated, 75,000 ha versus 30,000,000 ha (Anon. 1983c), notwithstanding the fact that the area of productive forest is six times greater than that of improved farmland (Anon. 1967 p. 752-754). Only 0.5% of all herbicides used in Canada today are used for forestry purposes. The point needs to be emphasized that forest weed control does not involve the treatment of large contiguous areas; rather, small islands scattered through oceans of untreated vegetation require infrequent treatment.

Frequency of Treatment

In agricultural practice, the same piece of land commonly receives some kind of weed control treatment year after year. Even in intensively managed forest, however, the need for weed control would be unlikely to arise more frequently than two or three times per cropping period of 50 to 100 years, provided that the treatment is effective and not transitory. The point here is that the frequency of treatment needed is a negative function of effectiveness, so that, for example, repeated manual weed control may be needed to obtain a degree of weed control obtainable with a single application of herbicides.

In agriculture, rather specific weed problems recur annually in relatively homogeneous soil-crop combinations. In familiar, recurring situations, the agriculturist is soon equipped to assess the need for weed control, to select among options, and to be able to predict the outcome with some confidence. By and large, the forester lacks this opportunity. On the one hand,

results of forest weed control treatments are less predictable and take longer to determine, and, on the other hand, recurrence of closely similar situations is infrequent.

If weed control treatment is applied in the absence of crop trees, e.g., for site preparation, the silvicultural response time is further increased by the delay between the application of the treatment and the subsequent introduction of the crop trees, for the benefit of which the weed control treatment was putatively undertaken.

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APPENDIX

Botanical names of plant species and genera mentioned in the text.

Common name	Botanical name
trembling aspen	*Populus tremuloides* Michx.
bamboo grass	*Sasa* spp.
bracken	*Pteridium aquilinum* (L.) Kuhn
cedar, eastern white	*Thuja occidentalis* L. spp.
cherry, black	*Prunus serotina* Ehrh.
cherry, pin	*P. pensylvanica* L.f.
fern, bracken	*Pteridium aquilinum* (L.) Kuhn
fern, hay-scented	*Dennstaedtia punctilobula* (Michx.) Moore
fern, New York	*Dryopteris noveboracensis* (L.) Gray
fern, sword	*Polystichum munitum* (Kaulf.) Presl
grass, bamboo	*Sasa* spp.
grass, crab	*Digitaria* Heist. spp.
grass, quack	*Agropyron repens* (L.) Beauv.
larch	*Larix* Mill. spp.
pine	*Pinus* L. spp.
pine, jack	*P. banksiana* Lamb.
pine, loblolly	*P. taeda* L.
pine, lodgepole	*P. contorta* Dougl. var. *latifolia* Engelm.
pine, red	*P. resinosa* Ait.
pine, white	*P. strobus* L.
poplar	*Populus* L. spp.
raspberry	*Rubus* L. spp.
spruce	*Picea* A. Dietr. spp.
spruce, black	*P. mariana* (Mill.) B.S.P.
spruce, white	*P. glauca* (Moench) Voss
walnut	*Juglans* L. spp.